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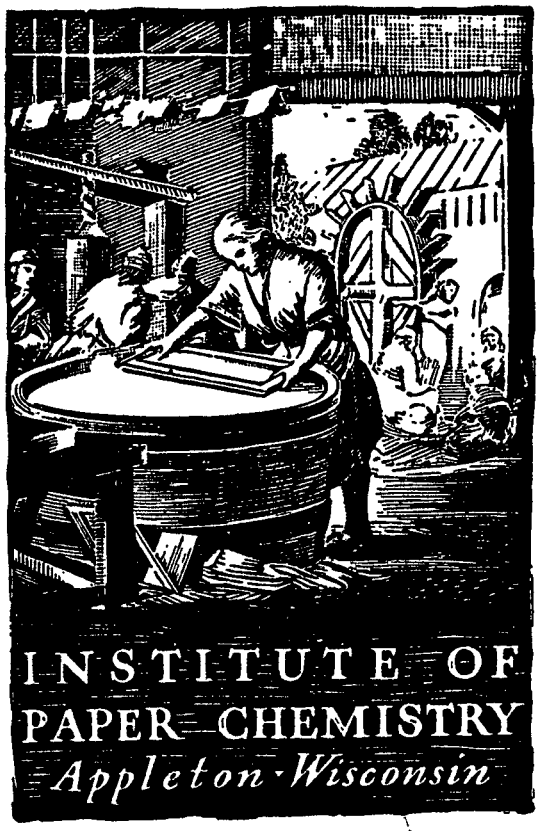

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Project 1108-3

Progress Report Five

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

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SUMMARY

Previous studies have shown that the stiffness of corrugated board, especially at high humidity, can be markedly increased by impregnating the corrugating medium, liners, or both with elemental sulfur.

This report describes a study of the behavior of untreated and sulfur-treated single-faced corrugated paperboard during a two-month exposure to relative humidities in excess of 80% at 40°F. A question had been raised as to whether the superiority of sulfur-treated corrugated would survive an extended exposure to high relative humidities.

Five samples of 26-lb. Chemfibre corrugating medium were fabricated into A-flute single-faced board with 42-lb. kraft linerboard and starch on the laboratory corrugator. Two of these mediums were untreated; the other three were treated with sulfur with 38, 56, and 70% sulfur pickups, respectively. As would be expected, the stiffness of untreated and sulfur-treated corrugated board decreased on prolonged exposure to a high relative humidity maintained at 40°F.; however, the sulfur-treated board was markedly superior as indicated by the following:

Moisture pickup determinations indicated that the superiority of sulfur-treated paperboard at high relative humidities prevails in spite of moisture contents which are nearly equal, in respect to fiber alone, to those present in ordinary paperboard at the same high relative

Flat crush test results indicated that the superiority of the sulfur-treated over the untreated board was generally greater at the high relative humidities than at 50% relative humidity. Moveover, the ratios indicate no sustained reduction in this superiority upon extended exposure to high relative humidities at 40°F.

The results of the single-faced board ring compression testing confirmed these conclusions. Although, in this test, the superiority of the sulfur-treated board was at first less at high relative humidities than at 50% relative humidity, the superiority of the sulfur-treated board generally increased during the extended exposure to high relative humidities until the superiority of the sulfur-treated board exceeded its 50% R.H. superiority over untreated board.

With respect to both flat crush and ring compression strength, the superiority of the sulfur-treated board over the untreated board was generally greater with the greater sulfur pickup.

INTRODUCTION

The Fourdrinier Kraft Board Institute, Inc., has initiated at The Institute of Paper Chemistry a co-operative program of investigation regarding the manufacture and utilization of sulfur-impregnated paperboard.

One of the first developments in this program was a method for applying molten sulfur to corrugating medium either as a separate operation or during the corrugating operation. It was found that combined board made with a sulfur-treated corrugated medium was generally stronger than ordinary combined board. Moreover, it was found that the sulfur-treated board retained a greater fraction of its strength under high relative humidity conditions than did the ordinary board.

However, it was suspected that these benefits might be temporary and that the superiority of the sulfur-treated corrugated medium might not survive extended exposure to high relative humidities.

The present report describes a study of the behavior of sulfur-treated corrugated paperboard during a two-month exposure to relative humidities in excess of 80% at 40°F.

MATERIALS

The materials tested in this study were five samples of single-faced, A-flute corrugated paperboard; in three of these, the corrugated medium was sulfur-treated. For each of the five samples,

42-lb. kraft linerboard was used as the single-face liner; the adhesive was starch. Each sample was fabricated on the laboratory corrugator at The Institute of Paper Chemistry. The corrugated mediums of the five samples were as follows:

File 139726--26-lb. Chemfibre, one side sulfur-treated during corrugating operation.

File 139727--same as 139726, but untreated.

File 140445--26-lb. Chemfibre, both sides sulfur-treated during rewinding.

File 140446--same as 140445, but untreated.

File 140492--same as 140445, except that diphenyl was used to increase sulfur application.

Each sample of single-faced corrugated board was cut into sheets 21 to 24 inches long (14-inch cross-machine width). These sheets were rearranged in random order and the required numbers of circular five-square-inch specimens (weight and flat crush test) and 20 x 4-inch ring compression test specimens were cut from the sheets. The circular specimens and the rectangular specimens were rearranged in random order. Subsequently, the specimens were used in the order of their accessibility.

PROCEDURE

All the specimens were exposed for at least 72 hours in wire trays suspended in an atmosphere at 20% R.H. and 73°F. Then, for each sample, five of the circular specimens were weighed, individually, on an analytical balance, at 20% R.H. and 73°F.

For each sample, ten circular specimens and ten rectangular specimens were exposed 48 hours in wire trays suspended in air at 50% R.H. and 73°F. Then the circular specimens were tested for flat crush and the rectangular specimens were tested for ring compression.

The weighed circular specimens and the remaining flat crush and single-faced board ring compression test specimens were moved from the 20% R.H. and 73°F. atmosphere to an atmosphere having a relative humidity in excess of 80% and a temperature of 40°F. At intervals during their nine weeks' exposure to this high relative humidity, the weight specimens were reweighed. After various periods of exposure, the flat crush specimens and the ring compression specimens were subjected to their respective tests (ten specimens at a time per sample, for each test). The flat crush testing was done in the high relative humidity atmosphere but the single-faced board ring compression test specimens were tested immediately upon exposure to 50% R.H. and 73°F.

The Hinde and Dauch compression testing machine was used for the flat crush testing; the platen-to-platen loading rate for this machine was 900 pounds per minute.

The single-faced board ring compression testing was performed on the Baldwin-Southwark universal testing machine with a testing speed of 0.5 inch per minute.

DISCUSSION OF RESULTS

From the weights of the circular five-square-inch specimens at 20% R.H. and 73°F., the basis weight and percentage sulfur pick-up data

were calculated (Table I). The percentage sulfur pickup was computed from the differences between the basis weights of the treated and untreated board. The basis weight of the corrugating medium was considered to be the nominal 26 pounds. Thus, the percentage sulfur pickup was computed by dividing 100 times the difference between the basis weights of the treated and untreated single-faced corrugated board by the basis weight of the corrugated medium (40.3 pounds). File No. 139727 board was used as the untreated version of File No. 139726 board and File No. 140446 board was used as the reference for File No. 140445 and 140492 boards.

TABLE I

WEIGHT AND SULFUR PICKUP
(20% R.H., 73°F.)

Institute File No.	Weight (Single-faced corrugated board --1000 sq. ft. basis), lb.	Sulfur Pickup (on the basis of the untreated corrugated medium alone), %
139726	98.5	38
139727	83.1	untreated
140445	105.6	56
140446	83.2	untreated
140492	111.5	70

Because of the limitations of the air-conditioning and control equipment available and because of other work in progress during the nine-week exposure period, it was not possible to maintain the high relative humidity air within the small range of relative humidities required to obtain substantially constant paperboard properties after extended exposure to relative humidities in excess of 80%. Furthermore, the five different

boards were not all introduced into the high relative humidity air at the same time. However, File 139726 and 139727 specimens were exposed to the high relative humidity air at the same time and the subsequent testing was done at the same times for the two boards. Therefore, inasmuch as the two boards were subjected to the same treatment before being tested, the results may be expected to indicate whether the superiority of sulfur-treated corrugating medium survives extended exposure to high relative humidities. Likewise, File 140445, 140446, and 140492 specimens were exposed to the high relative humidity air at the same time and the subsequent testing was done at the same times for these three boards. Therefore, the results for these three boards are also indicative of whether the superiority of sulfur-treated corrugated medium survives extended exposure to high relative humidities.

It should be stressed that the exposure and testing of File 139726 and 139727 specimens was three weeks ahead of that of File 140445, 140446, and 140492 specimens. In view of the fluctuation of the relative humidity of the high humidity air, the high relative humidity test results for the 56% and 70% sulfur-treated boards should not be compared with those for the 38% sulfur-treated board except through the results for the corresponding untreated boards.

Furthermore, it should be stressed that it was not always feasible to carry out the weighing, the flat crush testing, and the ring compression testing, simultaneously at each interval of exposure to high relative humidities. Therefore, in view of the fluctuation of the relative humidity of the

high relative humidity air, the weight, flat crush, and ring compression test results for a given board and high relative humidity exposure interval should not be compared.

The average percentage differences between the weights of the single-faced boards at 20% R.H. and 73°F. and the weights after various periods of exposure at the high relative humidities are shown in Table II. These differences have been attributed to increases in moisture content. Thus, the differences are expressed in terms of percentage moisture pickup on the basis of the weights at 20% R.H. and 73°F., the latter being the references for the determinations of the differences and the denominators in the determination of the percentages.

It may be seen from Table II that the percentage moisture pickup upon exposure to high relative humidities was generally less for the sulfur-treated board than for the untreated board. Furthermore, the percentage moisture pickup was generally less for board with the greater sulfur pickup. However, the percentage moisture pickup was computed on the basis of the whole weight of the paperboard, including the weight of the sulfur. Therefore, these data do not indicate whether the moisture pickup, on the basis of fiber alone, was reduced by the sulfur treatment.

In order to determine whether the moisture pickup, on the basis of fiber alone, was reduced by the sulfur treatment, the moisture pickup was converted from percentage to basis weight terms. Accordingly, in Table III the increases in moisture content upon exposure to high relative humidities are given in pounds per thousand square feet of single-faced

TABLE II

INCREASES IN MOISTURE CONTENT DURING EXPOSURE TO HIGH RELATIVE HUMIDITY

Institute File No.	Average Increase in Moisture Content, % 139727	139726	Ratio
Sulfur Pickup	Untreated	38%	38%/untreated
Time of Exposure to High Relative Humidity			
3 hours	11.1	9.6	0.86
6 hours	13.5	11.1	0.82
1 day	15.1	12.7	0.84
2 days	16.0	13.3	0.83
3 days	16.1	13.5	0.84
1 week	16.5	13.8	0.84
2 weeks	16.8	13.8[a]	0.82
3 weeks	17.9	14.9[a]	0.83
4 weeks	18.0	14.8[a]	0.82
5 weeks	21.5	17.5[a]	0.81
6 weeks	21.6	17.8[a]	0.82
7 weeks	21.3	17.8[a]	0.84
8 weeks	17.4	14.6[a]	0.84
9 weeks	18.2	14.9[a]	0.82

Institute File No.	140446	140445	Ratio	140492	Ratio
Sulfur Pickup	Untreated	56%	56%/untreated	70%	70%/untreated
Time of Exposure to High Relative Humidity					
3 hours	12.9	10.2	0.79	9.3	0.72
6 hours	15.5	11.7	0.75	11.0	0.71
1 day	17.1	13.0	0.76	12.4	0.73
2 days	17.4	13.3	0.76	12.6	0.72
3 days	17.7	13.5	0.76	12.8	0.72
1 week	17.3	13.3	0.77	12.5	0.72
2 weeks	21.8	16.5	0.76	15.7	0.72
3 weeks	21.6	16.5	0.76	15.5	0.72
4 weeks	21.8	16.6	0.76	15.7	0.72
5 weeks	16.6	12.9	0.78	11.9	0.72
6 weeks	18.1	13.8	0.76	13.2	0.73
7 weeks	19.9	15.3	0.77	14.3	0.72
8 weeks	19.3	14.9	0.77	13.8	0.72
9 weeks	20.3	15.4	0.76	14.8	0.73

[a] Average of only four instead of five specimens.

TABLE III

INCREASES IN MOISTURE CONTENT DURING EXPOSURE TO HIGH RELATIVE HUMIDITY

	Average Increase in Moisture Content, pounds/1000 sq. ft.[a]		
Institute File No.	139727	139726	Ratio
Sulfur Pickup	Untreated	38%	38%/Untreated
Time of Exposure to High Relative Humidity			
3 hours	9.2	9.5	1.03
6 hours	11.2	10.9	0.97
1 day	12.5	12.5	1.00
2 days	13.3	13.1	0.98
3 days	13.4	13.3	0.99
1 week	13.7	13.6	0.99
2 weeks	14.0	13.6[b]	0.97
3 weeks	14.9	14.7[b]	0.99
4 weeks	15.0	14.6[b]	0.97
5 weeks	17.9	17.2[b]	0.96
6 weeks	17.9	17.5[b]	0.98
7 weeks	17.7	17.5[b]	0.99
8 weeks	14.5	14.4[b]	0.99
9 weeks	15.1	14.7[b]	0.97

Institute File No.	140446	140445	Ratio	140492	Ratio
Sulfur Pickup	Untreated	56%	56%/untreated	70%	70%/untreated
Time of Exposure to High Relative Humidity					
3 hours	10.7	10.8	1.01	10.4	0.97
6 hours	12.9	12.4	0.96	12.3	0.95
1 day	14.2	13.7	0.96	13.8	0.97
2 days	14.5	14.0	0.97	14.0	0.97
3 days	14.7	14.3	0.97	14.3	0.97
1 week	14.4	14.0	0.97	13.9	0.97
2 weeks	18.1	17.4	0.96	17.5	0.97
3 weeks	18.0	17.4	0.97	17.3	0.96
4 weeks	18.1	17.5	0.97	17.5	0.97
5 weeks	13.8	13.6	0.99	13.3	0.96
6 weeks	15.1	14.6	0.97	14.7	0.97
7 weeks	16.6	16.2	0.98	15.9	0.96
8 weeks	16.1	15.7	0.98	15.4	0.96
9 weeks	16.9	16.3	0.96	16.5	0.98

[a] In addition to basis weight at 20% R.H., 73°F.
[b] Average of only four instead of five specimens.

board. It may be seen in Table III that the weight increase was generally only slightly less for the sulfur-treated board than for the untreated board. This is confirmed by the ratios of the moisture pickups of the sulfur-treated boards to those of the untreated board. Inasmuch as the basis weights of the boards were alike except for the sulfur content, this indicates that the moisture pickup, on the basis of fiber alone, was not greatly reduced by the sulfur treatment.

In the extreme instance in Table III, the ratio of the moisture pickup of the single-faced 70% sulfur-treated board to that of the untreated board was 0.95 upon 6 hours of exposure to high relative humidities. In view of the fact that only the corrugated medium (about half the fiber in the single-face board) was sulfur-treated, this indicates that the moisture pickup of the 70% sulfur-treated corrugated medium, on the basis of fiber alone, was nine tenths of that of the untreated corrugated medium, even in this extreme instance. Thus, it appears that the additional strength of sulfur-treated paperboard at high relative humidities prevails in spite of the moisture contents which are nearly equal, in respect to the fiber alone, to those present in ordinary paperboard at the same high relative humidities.

The average flat crush test values are shown in Table IV. The ratios of the average flat crush test values for the sulfur-treated board to those of the untreated boards are indicated in this table. These ratios indicate that the flat crush strength of single-faced corrugated board is increased by the sulfur treatment. Furthermore, the ratios indicate that the relative superiority of the sulfur-treated board was generally greater

TABLE IV

FLAT CRUSH TEST RESULTS

Institute File No.	Average Flat Crush, pounds per square inch: 139727 Untreated	139726 38%	Ratio 38%/untreated
Sulfur Pickup At 50% R.H., 73°F.	25.6(10)	30.8(10)	1.20
Time of Exposure to High Relative Humidity			
6 hours	17.3(0)	24.9(0)	1.44
1 day	13.5(0)	20.3(0)	1.50
2 days	12.5(0)	17.9(0)	1.43
1 week	12.6(5)	18.1(5)	1.44
2 weeks	12.4(6)	18.4(5)	1.48
3 weeks	13.1(7)	19.1(4)	1.46
4 weeks	13.5(6)	18.6(5)	1.38
5 weeks	10.8(7)	14.6(4)	1.35
6 weeks	11.1(7)	15.7(3)	1.41
7 weeks	11.6(4)	15.9(5)[a]	1.37
8 weeks	10.6(2)	14.9(8)	1.41
9 weeks	11.1(7)	15.5(5)	1.40

Institute File No.	140446 Untreated	140445 56%	Ratio 56%/untreated	140492 70%	Ratio 70%/untreated
Sulfur Pickup At 50% R.H., 73°F.	22.0(9)	30.9(5)	1.40	36.1(5)	1.64
Time of Exposure to High Relative Humidity					
6 hours	18.6(3)	30.6(1)	1.65	29.3(4)	1.58
1 day	13.4(3)	20.3(0)	1.51	21.9(2)	1.63
2 days	12.0(3)	16.2(3)	1.35	21.5(1)	1.79
1 week	12.9(8)	15.4(3)	1.19	20.5(5)	1.59
2 weeks	10.2(4)	13.1(3)	1.28	18.2(5)	1.78
3 weeks	11.3(10)	15.0(2)	1.33	20.3(2)	1.80
4 weeks	12.2(9)	14.9(10)	1.22	22.3(8)	1.83
5 weeks	12.4(9)	14.2(0)	1.15	16.2(4)	1.31
6 weeks	12.0(7)	14.7(3)	1.22	20.1(6)	1.68
7 weeks	8.2(9)	13.2(0)	1.61	17.7(3)	2.16
8 weeks	10.2(6)	14.6(1)	1.43	16.6(2)	1.63
9 weeks	9.1(5)	13.8(1)	1.52	17.7(4)	1.95

[a] Distinct peak loads were observed for only nine of the ten specimens tested.

Note: The figure in parentheses beside each average flat crush value indicates the number of specimens in which the flutes rolled during the test.

at the high relative humidities than at 50% R.H. Moreover, the ratios indicate no sustained reduction in this superiority upon extended exposure to high relative humidities at 40°F. This is shown graphically in Figures 1, 2, and 3 in which the average flat crush values for the untreated and 38, 56, and 70% sulfur-treated board are compared.

The average single-faced board ring compression test values are listed in Table V and illustrated in Figures 4, 5, and 6. The ratios of the average ring compression test values for the sulfur-treated board to those of the untreated boards are indicated in Table V. These ratios indicate that the ring compression strength of single-faced corrugated board is increased by sulfur treatment of the corrugating medium. Although the relative superiority of the sulfur-treated board was at first less at high relative humidities than at 50% R.H., the superiority of the sulfur-treated board generally increased during the extended exposure to high relative humidities until the superiority of the sulfur-treated board exceeded its 50% R.H. superiority over untreated board.

TABLE V

SINGLE-FACED RING COMPRESSION TEST RESULTS

Institute File No.	139727 Untreated	139726 38%	Ratio 38%/untreated
Sulfur Pickup			
At 50% R.H., 73°F.	496	663	1.33
Time of Exposure to High Relative Humidity			
6 hours	318	374	1.18
1 day	314	327	1.04
2 days	261	291	1.11
1 week	215	251	1.17
2 weeks	207	281	1.36
3 weeks	208	271	1.30
4 weeks	199	279	1.40
5 weeks	146	217	1.49
6 weeks	153	215	1.41
7 weeks	164	229	1.40
8 weeks	166	237	1.43
9 weeks	176	232	1.32

Institute File No.	140446 Untreated	140445 56%	Ratio 56%/untreated	140492 70%	Ratio 70%/untreated
Sulfur Pickup					
At 50% R.H., 73°F.	497	698	1.40	773	1.56
Time of Exposure to High Relative Humidity					
6 hours	347	436	1.26	469	1.35
1 day	219	315	1.44	378	1.73
2 days	176	284	1.61	342	1.94
1 week	179	280	1.56	349	1.95
2 weeks	145	214	1.48	249	1.72
3 weeks	145	220	1.52	269	1.86
4 weeks	148	235	1.59	282	1.91
5 weeks	162	257	1.59	312	1.93
6 weeks	159	263	1.65	303	1.91
7 weeks	134	242	1.81	275	2.05
8 weeks	125	265	2.12	300	2.40
9 weeks	129	251	1.95	297	2.30

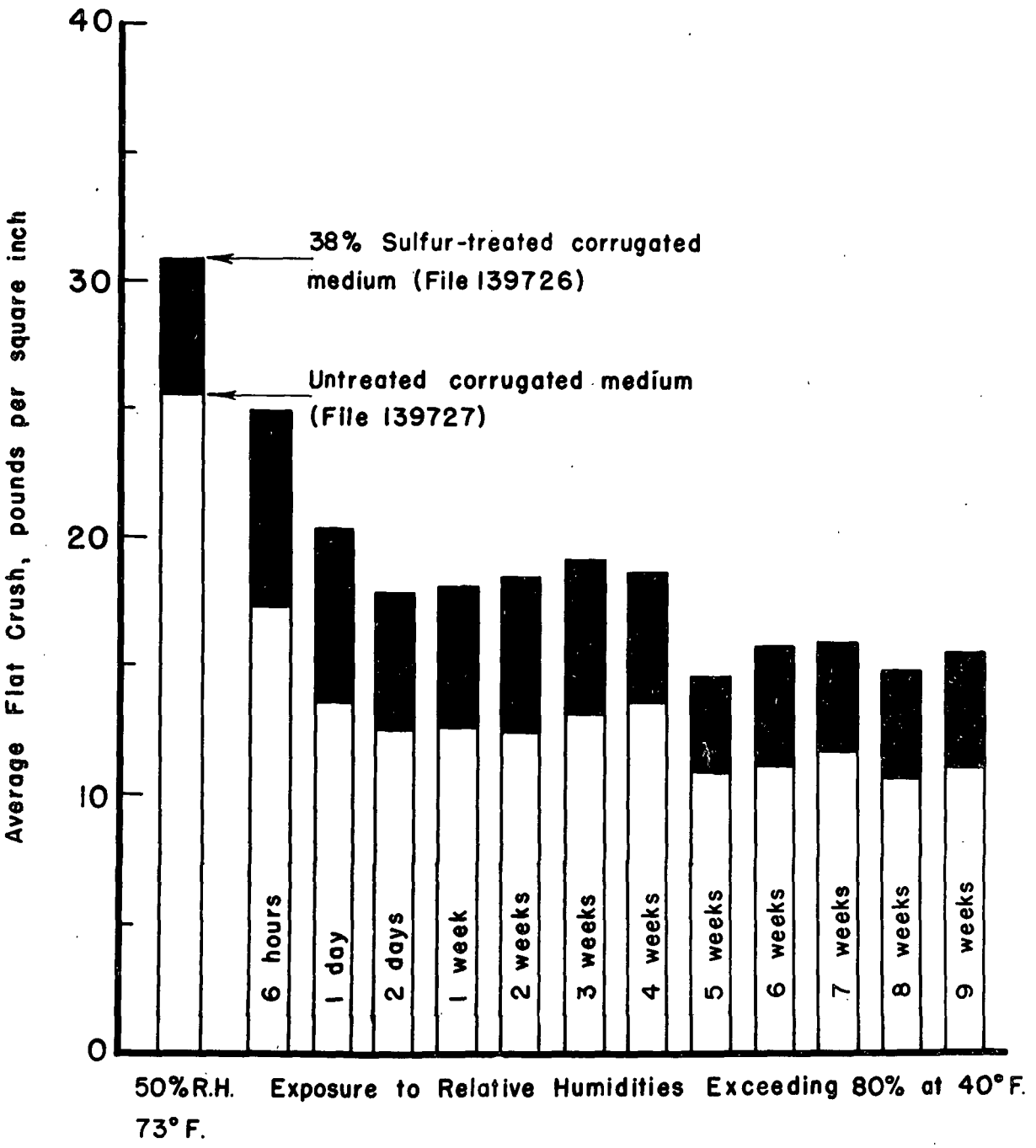

Figure 1

Flat Crush Test Results for Untreated
and 38% Sulfur-treated
Corrugated Mediums

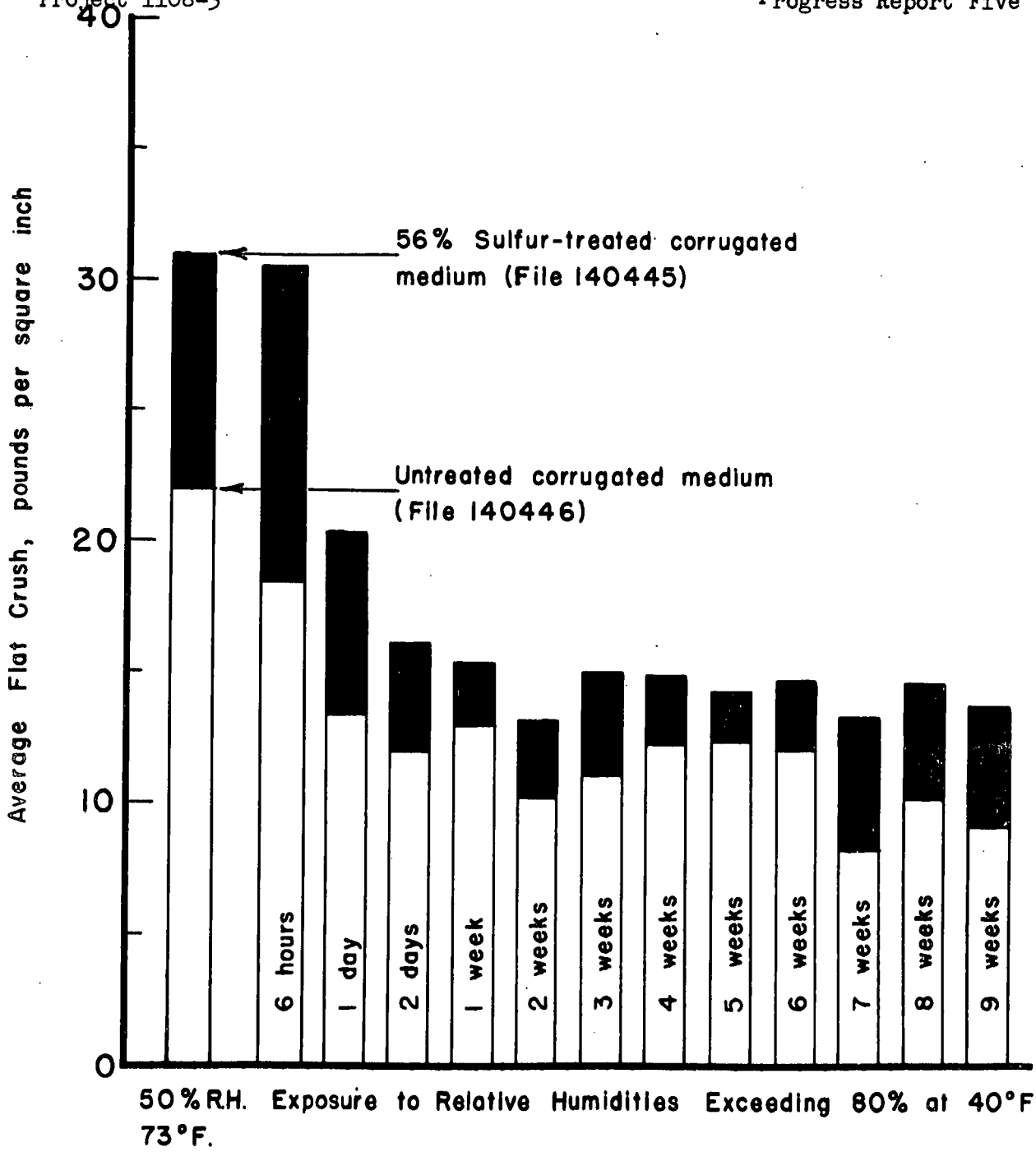

Figure 2

Flat Crush Test Results for Untreated
and 56% Sulfur-treated
Corrugated Mediums

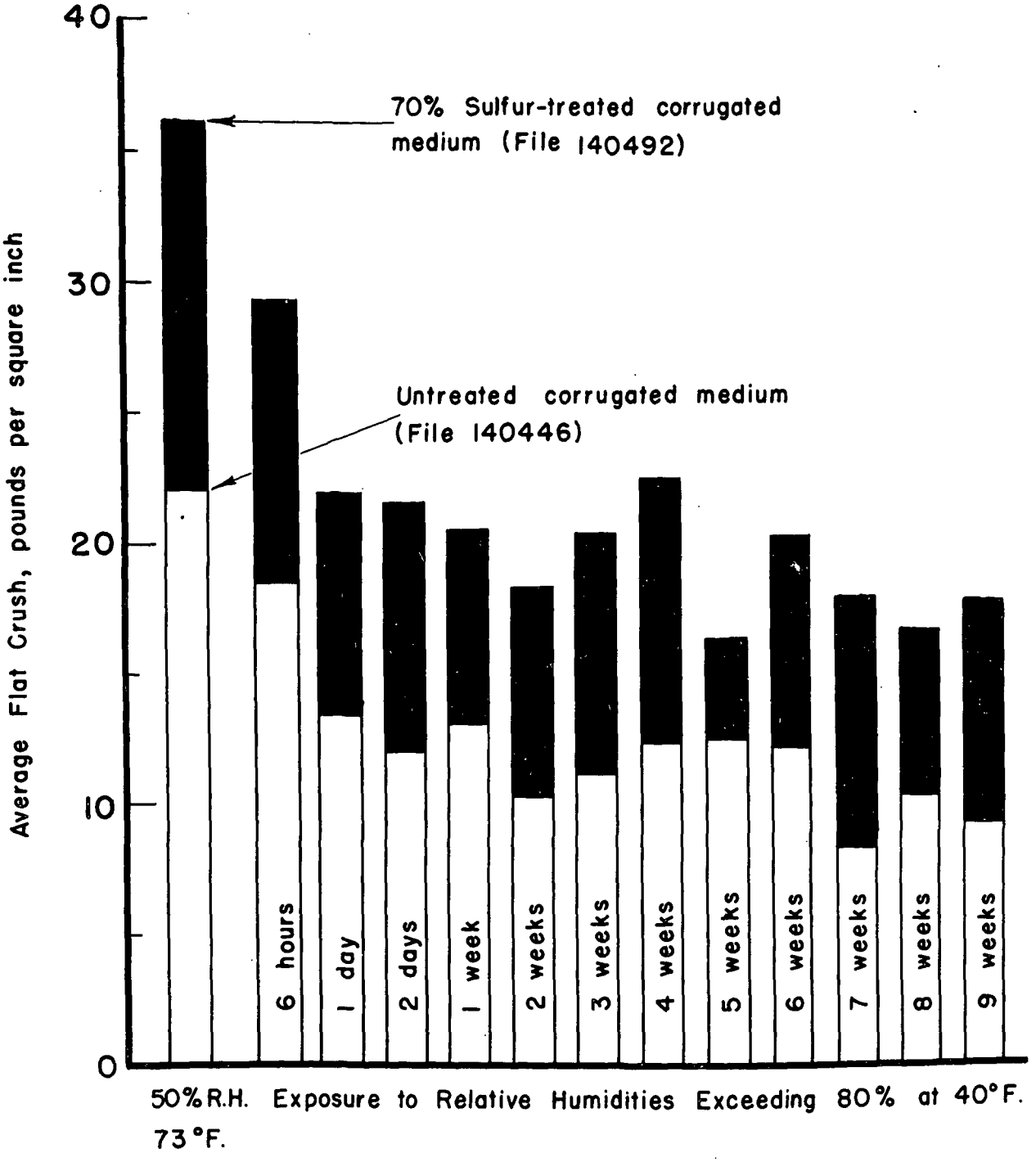

Figure 3

Flat Crush Test Results for Untreated
and 70% Sulfur-treated
Corrugated Mediums

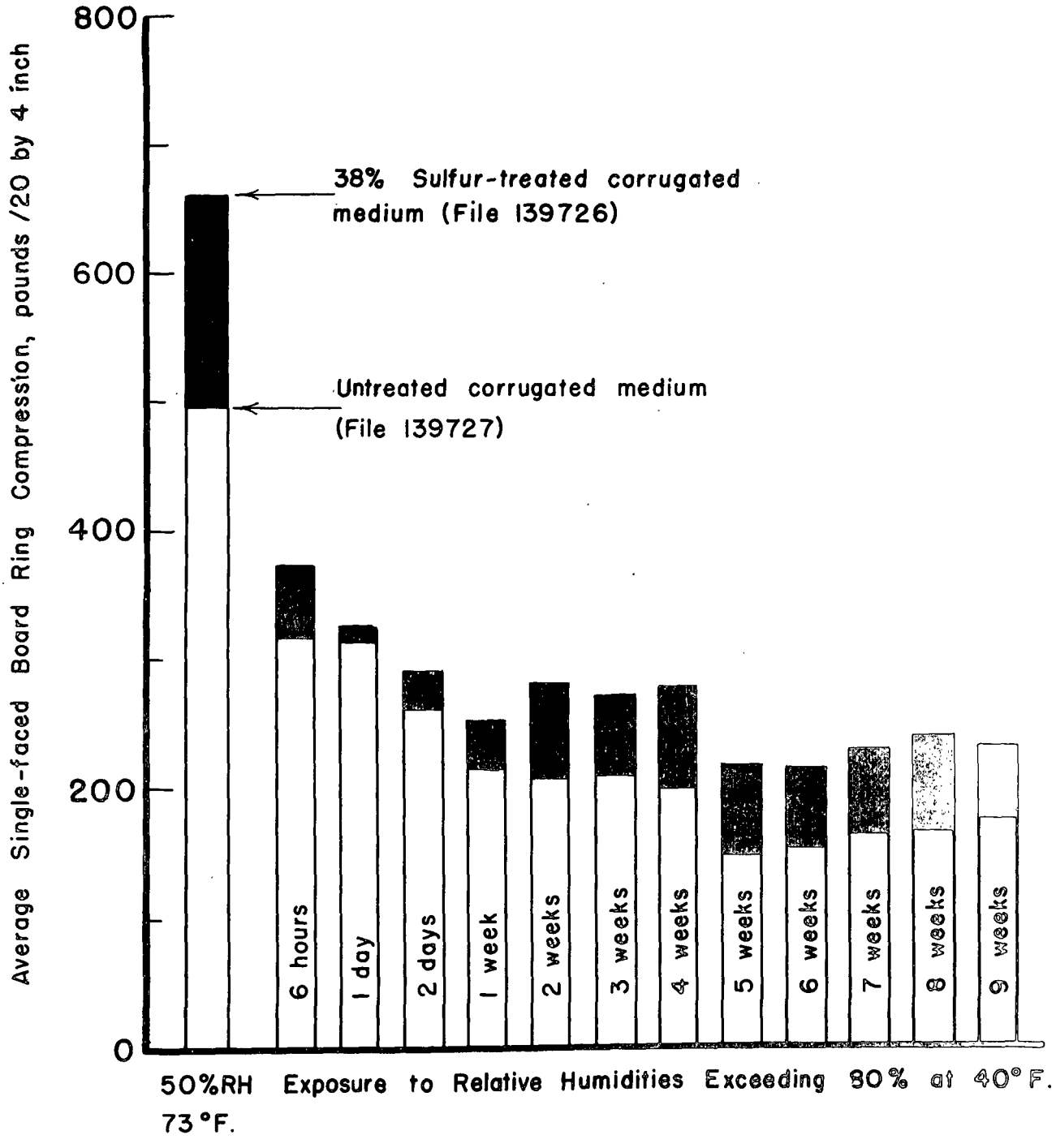

Figure 4

Single-faced Board Ring Compression Test Results for Untreated and 38% Sulfur-treated Corrugated Mediums

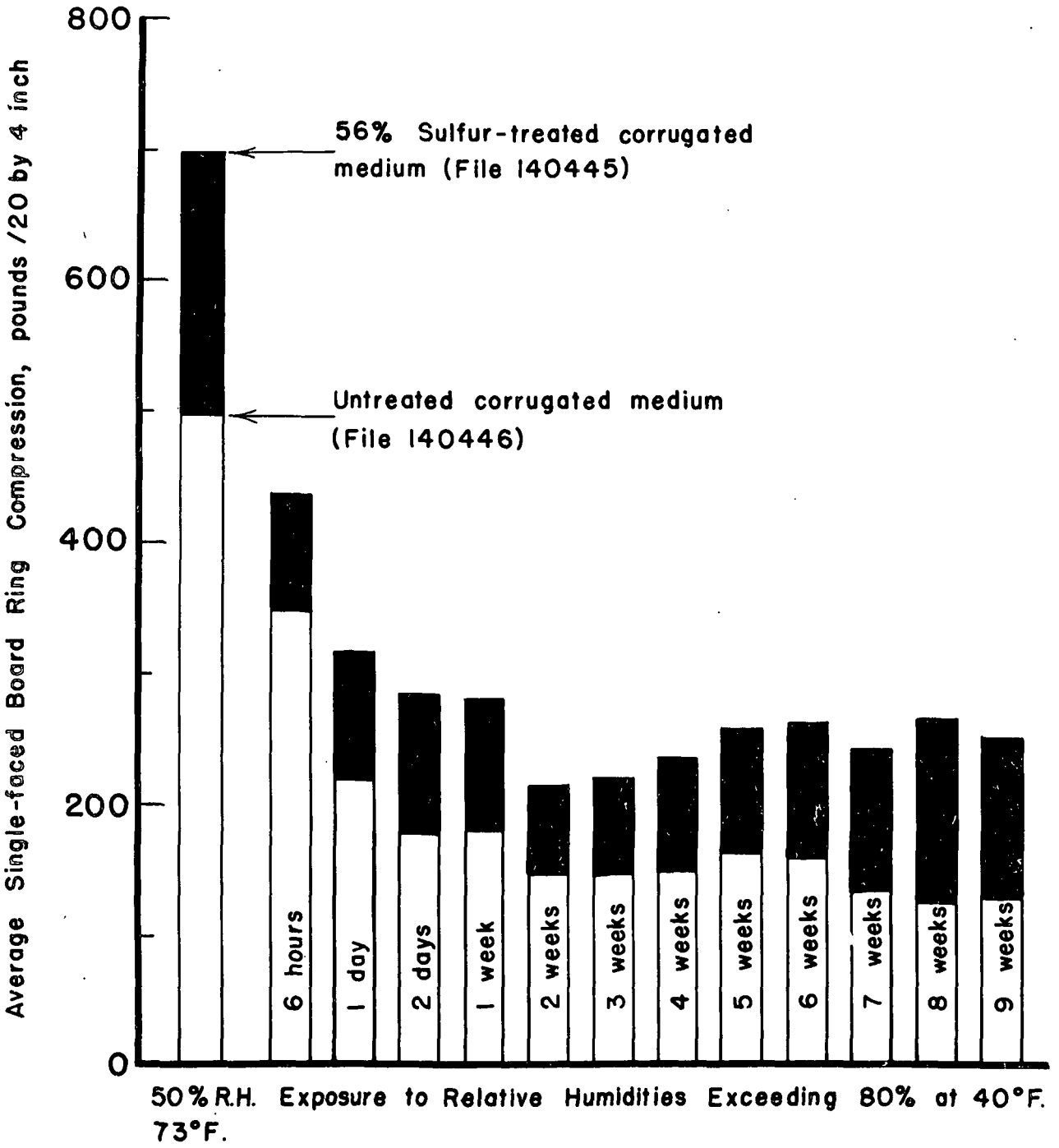

Figure 5

Single-faced Board Ring Compression Test Results for Untreated and 56% Sulfur-treated Corrugated Mediums

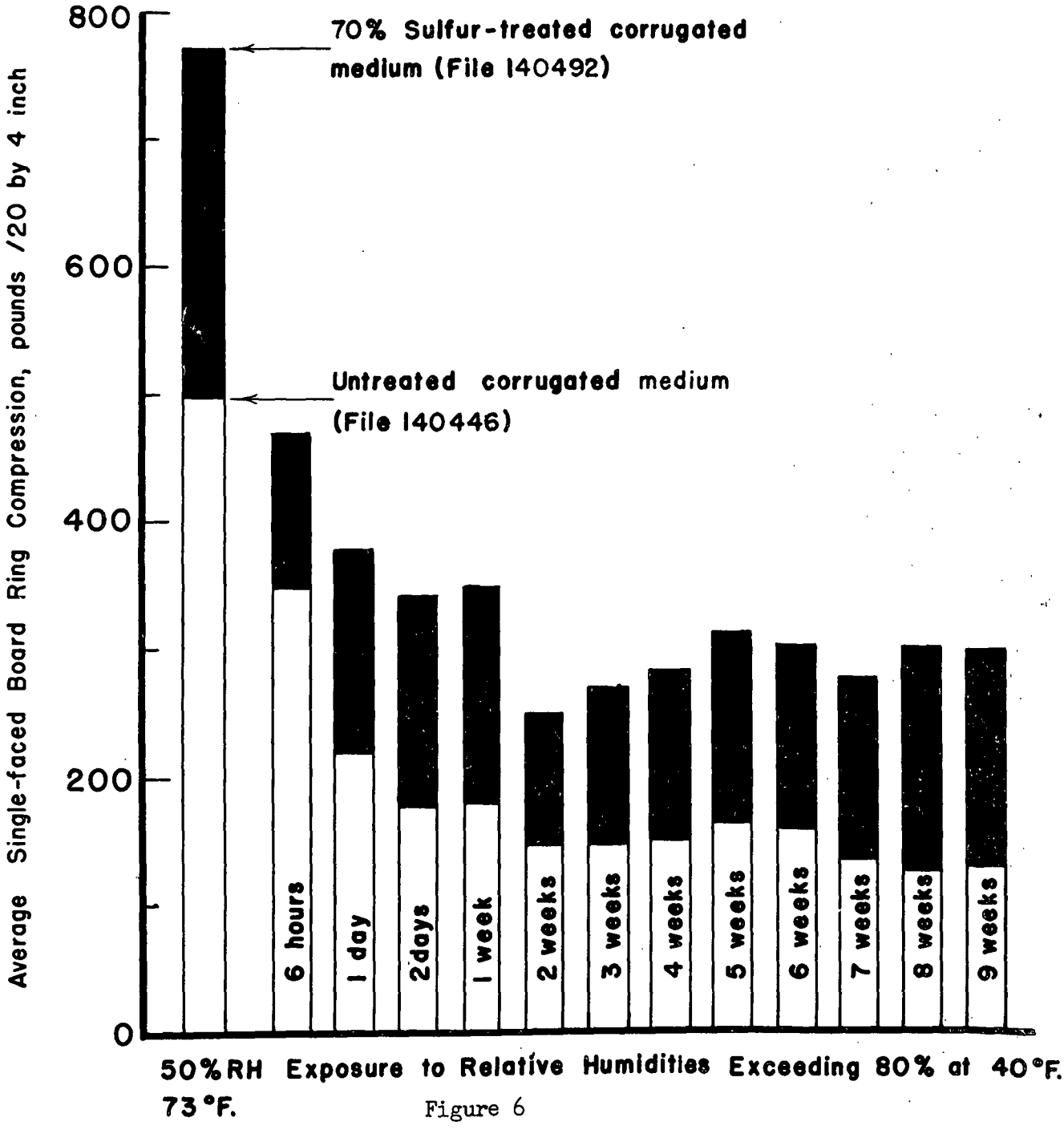

Figure 6

Single-faced Board Ring Compression Test Results for Untreated and 70% Sulfur-treated Corrugated Mediums